Industrial Engineering & Management

Claypool et al., Ind Eng Manage 2015, 4:2
DOI: 10.4172/2169-0316.1000156

Research Article Open Access

Design for Supply Chain: An Analysis of Key Risk Factors

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Abstract

The objective of Design for Supply Chain (DFSC) is to design a new product and its corresponding supply chain in a simultaneous manner. Several DFSC models have been developed by previous researchers. However, companies also need to manage the risks associated with both the product design and the supply chain. Many of the previous DFSC models do not consider risk. To determine which risk factors should be included in DFSC models, a survey was developed and administered to industry experts. 29 supply chain risk factors and 21 new product development (NPD) risk factors were included in the survey. This paper shows the process that was used to develop this survey and presents its results. The survey identified a list of the top ten risk factors which includes inventory management/stock out risk, strategic exposure risk, market/demand risks, capacity risks, risk of poor supplier reliability, organizational and project management risks, commercial viability risks, marketing proficiency, supply chain and sourcing risks and financial risks.

Keywords: Risk management; Design for supply chain

Introduction

The objective of this research is focused on the determination of the most critical risk factors related to new product development (NPD) and supply chain design decisions. Observations from the literature were used to identify these risk factors and then a survey of industry experts was used to identify candidate risk factors for future modeling. Finally, a statistical analysis of survey results was completed to select a set of critical risk factors to be included in a comprehensive risk assessment model.

In today's highly competitive and globalized market, manufacturing firms are placing an emphasis on efficiency and cost effectiveness. Cost-cutting initiatives are present throughout the business process–in design, manufacturing and the disposal of products. Outsourcing, focusing on sustainability, and recycling are some popular methods used for achieving these goals. Another method that is gaining popularity is a concept known as Design for Supply Chain (DFSC).

The objective of the DFSC methodology is to design a product's supply chain in parallel to designing or redesigning a product. Traditionally, the supply chain is designed after the product design phase has been completed, which often results in a longer cycle time and sub-optimal product profitability. Significant productivity improvements and cost reductions can be achieved by collaborating with supply chain engineers early in the design process [1]. Even more efficiencies can be realized when risk is also considered.

Risk has been defined by Lowrance as a "measure of the probability and severity of adverse effects [2]." In this research, risks are referred to as events, which if they occur, will have detrimental impacts to the product or supply chain. Risk is an inherent element of the DFSC process, but consideration for risk is limited with current DFSC models [3-7]. Many analytical risk models and commercial tools have been developed to help companies identify, quantify and mitigate risks related to either supply chain or product design. Even though many supply chain risk models and many NPD risk models are available, there are few models that consider both aspects simultaneously. Chaduri et al. attempts to close this gap. They consider supplier, process, logistics and manufacturing capacity risks that are present in the NPD process. These risks are analyzed using numeric and linguistic data in a group decision making environment. They also utilize FMEA to prioritize the risks. The limitation with their work is that it requires involvement from customers and suppliers which is not always possible [8]. For a company to actively compete in today's global economy it is very important to manage cost, quality, efficiency, and also risk. A survey by Accenture, found that 110 of 151 U.S. supply chain executives said that their companies faced supply chain disruptions in the past five years [9]. Similarly, most new products never reach the market, and those that do suffer failure rates around 25-45% [10]. A comprehensive research effort was completed to develop a combination DFSC and risk tool that looks at design, supply chain and risk concurrently [11-14]. This research and paper contributed to that larger research effort by providing an analysis of relevant NPD and supply chain risk factors. The most critical risk factors were identified and then included in the DFSC and risk model.

Literature Review

The supply chain risk management and NPD risk management bodies of scholarly literature were examined to determine which risk factors have been studied, analyzed and modeled in the past. The purpose was to identify the most commonly cited risk factors that would serve as the basis to create a survey on supply chain and NPD risk factors to be given to representatives from industry. It is interesting to note that research published after the risk survey was executed also identified many of the same supply chain and NPD risk factors [15-19].

Diabat et al. created a model using interpretive structural modeling (ISM) to analyze risks involved in a food supply chain [15]. They included demand, supply, product/service, and information risks. Samvedi et al. quantifies risks, in the broad categories of supply, demand, process, and environmental risks, using fuzzy AHP and fuzzy TOPSIS [16]. Viswanadham and Samvedi present a two-step approach to the supplier selection problem, using fuzzy AHP and fuzzy TOPSIS.

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Received March 07, 2014; **Accepted** April 13, 2015; **Published** May 13, 2015

Citation: Claypool EG, Norman BA, Needy KL (2015) Design for Supply Chain: An Analysis of Key Risk Factors. Ind Eng Manage 4: 156. doi:10.4172/2169-0316.1000156

They include supply chain risks, resource related risks, institutional risks, and delivery infrastructure risks [17].

Aqlan and Lam conduct a survey of risk factors and then use Bow-Tie analysis and a fuzzy interface system (FIS) to determine total risk scores for each risk factor. Their survey includes some of the same risk factors identified in this research, including the broad categories of supplier risks, customer risks, technology risks, and commodity risks [18]. Inman and Blumenfeld model the impact of product complexity and supply chain design. This model includes supply chain disruption risks [19].

Supply chain risk management

Risk in the supply chain refers to uncertain or unpredictable events that can negatively affect supply chain functionality or profitability. The purpose of supply chain risk management is to reduce the impact of these risks by developing methods and models to identify, assess and mitigate risk. There is a vast amount of literature in this body of knowledge because it is a very broad field encompassing many different decisions [20,21]. These include facility location, transportation planning, supplier selection, inventory positioning and design of the supporting information systems.

This research was only focused on the supplier selection decision, which entails choosing suppliers for raw materials sourcing. There are many factors to consider in this decision including cost, quality, reputation, location, lead time, capacity, etc. [22]. A summary of the supplier selection literature review and the corresponding risk factors that were modeled in each article is contained in Table 1. Risk factors depicting "0" number of articles, were discussed in the literature but not explicitly modeled in a quantitative supply chain model.

NPD risk management

Risk in NPD has been defined as "the probability that the product will not satisfy all of its requirements" [23-58]. The process of developing a new product is also faced with a multitude of risks. If a NPD team can identify and manage these design risks, the product is more likely to be successful. The NPD risk management literature review is summarized in Table 2 along with the corresponding design risks identified in each article.

Risk management summary

The review of literature revealed that for supply chain risks, lead time variation risk, the risk of poor supplier reliability, and the risk of quality problems are modeled most frequently in the literature. In the

Risk	Description	# of Articles and Sources	
1. Lead Time Variation Risk	Lead times of products fluctuate greatly.	13	[23-35]
2. Quality Problems	Product does not meet quality standards.	11	[23-24,27-29,31,34,36-39]
3. Risk of Poor Supplier Reliability	Inability of supplier to provide quality product in a timely manner.	10	[23-25,31-34,40-42]
4. Exchange Rate Risk	Risk that investment's value will be affected by exchange rate changes.	7	[24,33,43-47]
5. Market/Demand Risks	Changes in the market affect demand or value of product (e.g., seasonality).	6	[25,33,38,43,48-49]
6. Manufacturing/Production Problems	Risk of machine breakdowns, quality issues, etc.	4	[25,32,47,49]
7. International Terrorism	Risk of terrorism.	3	[25,47,50]
8. Capacity Risk	Risk of production capacity shortage.	3	[25,37,42]
9. Financial Health of Suppliers	Supplier is at risk of bankruptcy.	3	[25,31,42]
10. Natural Disasters	Risk of hurricane, flood, etc.	2	[25,47]
11. Strategic Exposure Risk	Over-reliance on a single or limited number of suppliers.	2	[24,49]
12. Political Environment/Instability	Risk that political turmoil impacts a supplier's business.	1	[50]
13. Demand/Forecast Risk	Risk of forecasting errors.	1	[25]
14. Transportation Risk	Delay in inbound or outbound transportation of goods.	1	[25]
15. Information Security Risks	Disclosure of information to unauthorized persons.	1	[32]
16. Inventory Management/Stockout Risk	Risk that inventory will not be available.	1	[32]
17. Development Risk	Difficulty transitioning to new products, suppliers or processes.	1	[32]
18. Information Technology (IT) Failure	Risk of IT failure that disrupts supply chain performance.	1	[32]
19. Key Staff Loss	Risk of strike, retirees, layoffs, etc.	1	[47]
20. Infectious Disease	Risk of bird flu, SARS, etc.	1	[47]
21. Information Distortion and Bullwhip Risks	Risk that supplier orders fluctuate more than customer sales.	0	
22. Outsourcing Risk	Risks associated with outsourcing.	0	
23. Cash Flow Risk	Risk of poor flow of cash.	0	
24. Technology Shift	Risk of shift in technology.	0	
25. Brand Erosion	Loss in profit from poor reputation.	0	
26. Environmental Requirements	Risk of unforeseen requirements.	0	
27. Fraud	Risk of fraudulent activity.	0	
28. Higher Energy Costs	Risk that increase in energy costs causes supplier costs to rise.	0	
29. Regulatory Requirements	Risk of unforeseen requirements.	0	

Table 1: Supply Chain Risk Factors in the Literature.

Risk	Description	# of Articles and Sources	
1. Product Technology Risk	New product fails to fulfill intended functions, or meet safety and technical requirements.	4	[51-54]
2. Supply Chain and Sourcing Risks	Risk that suppliers will have a problem with quality, capacity, finances, etc.	2	[54-55]
3. Time-to-Market Risk	Schedule risk.	2	[56-57]
4. Organizational and Project Management Risks	Risk of inadequate resources, poor management support, infeasible goals, ineffective team, etc.	1	[52]
5. Customer Acceptance Risks	Risk that product specifications will not meet customer demands and standards.	1	[54]
6. Financial Risk	Risk of issues with budget, loans, cash flow,incorrect pricing,inadequate sales, etc.	1	[40]
7. Outsourcing Risk	Any risk associated with the outsourcing of design or production-lead time, quality, language barriers, etc.	1	[58]
8. Manufacturing Technology Risks	Risk that raw materials are unavailable, production means not available, production standards will not be met, etc.	1	[54]
9. Intellectual Property Risks	Risk that original know-how will not be protected, relevant patent issues not understood, etc.	0	
10. Public Acceptance Risks	Risk of problem with the Public Relations of the project.	0	
11. Market Research Risk	Risk that data might be inaccurate or outdated.	0	
12. Information Security Risks	Risk of disclosure of information to unauthorized persons.	0	
13. Company Resources	Risk of inadequate capital, manufacturing facilities, manpower, etc.	0	
14. Market Competitiveness	Risk that product will not provide clear competitive advantage.	0	
15. Marketing Proficiency	Risk of inadequate market development, market launch, market research and testing.	0	
16. Internal/ External Communications	Risk of poor coordination and cooperation within the firm and between firms.	0	
17. Customer Service Efficiency	Risk of poor efficiency of manufacturing services, technical services, etc.	0	
18. Technological Exposure Risk	Over-reliance on a single or limited source of a product, process or technology.	0	
19. Product Family and Brand Positioning Risk	Risk that product fails to achieve business strategy, or have brand development potential.	0	
20. Legislation/Compliance Risk	Risk that product is not compliant with standards or legal issues arise with competitors.	0	
21. Commercial Viability Risks	Risk that market target is not clearly defined or that market potential is not attained.	0	

Table 2: NPD Risk Factors in the Literature.

Company	Description	Number of Responses
1	Manufacturer of materials testing and process heating equipment	5
2	Manufacturer of pumps, motors, generators, and control rod drive mechanisms	2
3	Designer and manufacturer of underground mining machinery	10
4	Manufacturer of engraving products	4
5	Manufacturer of medical imaging devices	3
6	Manufacturer of sleep and respiratory products	3
7	Manufacturer of high-end analytical instruments, laboratory equipment, and software	13
8	Provider of services and equipment to utility and industrial customers in the nuclear electric power industry	5
9	Designer and manufacturer of material handling robots	1
TOTAL		46

Table 3: Companies in Industry Survey.

NPD area, product technology risks and supply chain/sourcing risks were found most often. Although these risks were commonly found in the literature, they may not be the most important risks to consider in a DFSC model. Therefore, a sample of professionals was surveyed to gather more information.

Industry Survey Design

The 50 risk categories identified in the literature were used to create a risk survey. This survey was distributed to seventeen companies, from several different industries. Responses were received from nine companies, most of which were manufacturing companies located in the United States. Survey participants from each company had either a NPD or a supply chain related role in their company. Table 3 provides a brief description of each company that survey responses were received from. A similar technique was used by Thun and Hoenig [59]; however their survey was focused only on supply chain risk factors in the German automotive industry. This survey included supply chain and NPD risk factors. A risk survey was also performed by Chen et al., [60].

The survey was created in an electronic format to facilitate efficient data collection and analysis. An online survey creation tool called Survey Monkey was used, because it fit the data collection and analysis needs, and enabled easy distribution and collection of the survey via the internet. A complete copy of the survey with complete definitions of each risk factor can be found in [11].

Risk factors were evaluated on two different criteria–the Likelihood of Occurrence and the Impact of Occurrence. The reason for this is that some risk factors have a very significant impact when they occur, but are not very likely to occur; such as natural disasters. In the same regard, some risk factors are very likely to occur, but their effects are less significant. Risk factors that scored highly in both categories were regarded as those that are most important to consider. The Impact of Occurrence and Likelihood of Occurrence criteria were each evaluated on a four point scale – low (1), medium (2), high (3) and very high (4).“Unable to answer” was also an option for each question.

The survey was divided into two sections. Section One included

Citation: Claypool EG, Norman BA, Needy KL (2015) Design for Supply Chain: An Analysis of Key Risk Factors. Ind Eng Manage 4: 156. doi:10.4172/2169-0316.1000156

	Supply Chain			New Product Development		
Impact of Risk	0-15 yrs	N=22	Correlation=0.636	0-15 yrs	N=13	Correlation=0.656
	15+ yrs	N=13		15+ yrs	N=11	
Likelihood of Occurrence	0-15 yrs	N=22	Correlation=0.869	0-15 yrs	N=13	Correlation=0.812
	15+ yrs	N=13		15+ yrs	N=11	

Table 4: Correlation Analysis Results.

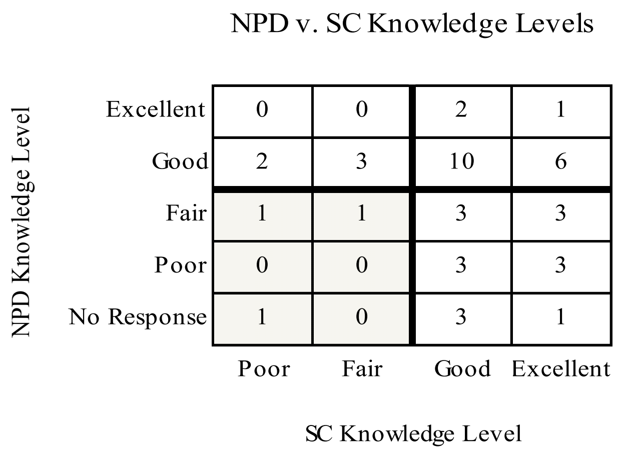
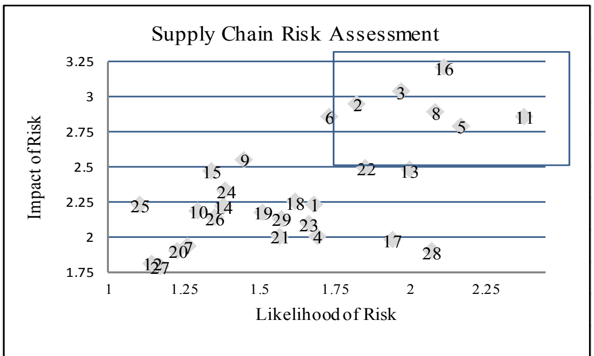


Figure 1: NPD vs. Supply Chain Knowledge Levels.



Risk		Impact		Likelihood	
		Avg	Sdev	Avg	Sdev
2	Quality Problems	2.94	0.84	1.83	0.71
3	Supplier Reliability	3.03	0.71	1.97	0.79
5	Market/Demand Risks	2.79	0.83	2.17	0.89
6	Manufacturing/Production Problems	2.85	0.86	1.74	0.75
8	Capacity Risk	2.88	0.77	2.09	0.87
11	Strategic Exposure Risk	2.85	1.05	2.38	1.04
13	Demand Forecast Risk	2.47	0.92	2.00	0.76
16	Inventory Management / Stockout Risk	3.20	0.63	2.11	0.90
22	Outsourcing Risk	2.49	0.95	1.86	0.77

Figure 2: Supply Chain Risk Scatter Plot.

29 supply chain risk factors and Section Two included 21 NPD risk factors. Before respondents evaluated the risk factors they were asked to provide their number of years experience with supply chain and/or NPD and also rate their knowledge in each field as either poor, fair, good or excellent. If a respondent rated them self as either poor or fair, the survey tool automatically skipped the corresponding risk evaluation section because the respondent's opinions were assumed to be of limited value. Respondents were also asked to indicate their company name, so response rates could be tracked by company.

Survey Results

Survey responses were received from 46 participants, as shown in Table 3. 3 of the 46 surveys returned were not filled out completely, so those responses were discarded. This resulted in 43 completed surveys. Within these 43 responses, 35 respondents rated their supply chain knowledge as excellent or good and thus assessed the supply chain risk factors. Similarly, 24 of the 43 respondents completed the NPD section. Figure 1 shows a breakdown of the 43 respondents with regard to their NPD and supply chain knowledge level ratings. Three respondents rated themselves as fair or poor in both categories, and were not permitted to rank either group of risk factors. Therefore, there were only 40 valid responses.

The breakdown of respondents by years of experience was also useful to analyze, through correlation analysis. To test the correlations between age groups of respondents, the respondents were split into two groups, a younger group with 0-15 years experience and an older group with greater than 15 years experience. The correlation analysis results are shown in Table 4. The Likelihood of Occurrence correlation values were fairly high, at 0.869 for supply chain and 0.812 for NPD. The Impact of Risk correlation values were not as high, so separate Impact of Risk populations were analyzed in addition to the entire population.

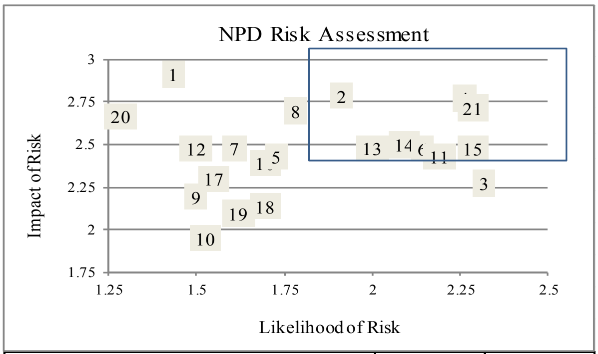
Next the risk factors were analyzed to determine which were considered most important from an industry perspective. Scatter plots were assembled by plotting the Likelihood of Occurrence averages against the Impact of Risk averages. Separate plots were constructed for supply chain and NPD risks. These are shown in Figures 2 and 3. Data points in the upper right quadrant of the plots were identified to be high ranking risks. This quadrant was found by calculating the midpoint of the range in average values for Impact and Likelihood. Then, a box was drawn around all points that were above the midpoint on both axes. Each data point is labeled with a number to identify the risk factor. A complete list of numbered risk factors is found in Tables 1 and 2.

It is interesting to note that of the supply chain risk factors in Figure 2, the risk of poor supplier reliability and the risk of quality problems are both highly ranked. These risk factors also appeared frequently in the literature. Of the NPD risk factors, in the upper right quadrant of Figure 3, supply chain and sourcing risks was found frequently in the literature.

As determined previously, the Impact of Risk ratings from the survey participants with less than 15 years experience were not correlated well with the ratings from survey participants who had more than 15 years experience. Therefore, scatter plots were also assembled for each of these smaller populations. These plots revealed almost identical "top risks" as those identified from the entire population.

Selection of Risk Factors

The scatter plots were useful in identifying a group of candidate risk factors for modeling. A limitation with the scatter plots was that Impact



Risk		Impact		Likelihood	
		Avg	Sdev	Avg	Sdev
2	Supply Chain and Sourcing	2.78	0.80	1.91	0.60
4	Organizational and Project Mgmt Risks	2.77	0.75	2.26	0.81
6	Financial Risk	2.48	1.03	2.14	0.73
11	Market Research Risk	2.43	1.03	2.19	1.12
13	Company Resources	2.48	0.85	2.00	0.85
14	Market Competitiveness	2.50	0.67	2.09	0.75
15	Marketing Proficiency	2.48	0.81	2.29	0.96
21	Commercial Viability	2.71	0.85	2.29	0.72

Figure 3: NPD Risk Scatter Plot.

Rank	I	L	I + L	2I + L	I + 2L	I × L	I^2× L	I × L^2
1	16	11	16	16	11	11	16	11
2	3	23	11	11	16	16	11	16
3	2	16	3	3	5	5	3	5
4	8	1	8	8	8	8	8	8
5	6	5	5	5	3	3	5	3
6	11	28	2	2	2	2	2	13
7	5	8	6	6	13	6	6	2
8	9	18	13	13	6	13	13	6
9	22	3	22	22	22	22	22	22
10	13	19	9	9	28	28	9	28

Table 5: Supply Chain Combination Measure Analysis.

and Likelihood were assumed to have equal weights of importance; however, this need not be the case. Given that Impact and Likelihood are two different dimensions of risk, it is not immediately evident how these two measures should be combined into one measure. One approach is to apply different weights to each of the measures and then combine them into one objective. Therefore, a quantitative analysis was conducted by considering several different weighting schemes. Risk factors that ranked highly in a majority of these weighting schemes were considered important risk factors.

The following combination measures were evaluated, where I=Impact Average and L=Likelihood Average: I, L, I + L, 2I + L, I + 2L, I × L, $I^2 \times L$, $I \times L^2$. Individual I and L measures were considered to see if the individual measures gave different results than the combined measures. I + L is a simple combination measure that weights each measure equally. 2I + L and I + 2L give more weight to impact and likelihood, respectively. Similarly, I×L is a simple product combination of I and L that captures potential interactions between the two measures. It is similar to taking an expectation as it multiplies impact with likelihood. $I^2\times L$ and $I\times L^2$ also have the flavor of an expectation but give more weight to impact and likelihood, respectively.

Supply chain risk factor analysis

Table 5 shows which supply chain risks were ranked in the top ten positions for each of the different combination measures. The numbers given in the table correspond to risk factors listed in Table 1. A visual examination of the table shows that risks consistently scoring highly among all combination measures were (16) inventory management/ stock out risks, (8) capacity risk, (3) supplier reliability, (11) strategic exposure risk and (5) market/demand risks.

The combination measures that were the most inconsistent among all results were I and L. A closer examination of the raw Impact and raw Likelihood values showed that the survey participants almost always gave a higher Impact rating than a Likelihood rating for each risk factor. To account for this, the Likelihood values were multiplied by a factor of 1.42 to normalize the data. This factor was obtained by dividing the overall Impact average of 2.33 by the overall Likelihood average of 1.64. Then, all of the combination measures in Table 5 were recalculated using the normalized data set and the same risks appeared consistently in the top positions.

Table 5 showed that risk factors 3, 5, 8, 11 and 16 are all ranked highly, but their order was not clear. To determine this, a simple metric was used. The sum of the rank positions for each combination measure was calculated. In other words, risk #11 had a score of 15, by the following calculation: 6 + 1 + 2 + 2 + 1 + 1 + 2 + 1=16, where 6 was the rank position for the first combination measure, 1 was the rank position for the second combination measure, etc. If a risk factor was not in one of the top ten positions for a certain combination measure, then a score of 11 was assumed for that column. The risk with the lowest overall score was the top risk. Table 6 shows the results of this analysis for the supply chain risk factors.

These results confirmed that risks 3, 5, 8, 11 and 16 were ranked highest and risks 11 and 16 were consistently ranked higher than 3, 5 and 8.

New product development risk factor analysis

The same analysis was completed for NPD risk factors. Those results are shown in Table 7. Risk factors that appeared to score highly across all combination measures were (11) market research risk, (15)

Overall Rank	Non-Normalized Data		Normalized Data	
	Including all Columns	Excluding Columns I and L	Including all Columns	Excluding Columns I and L
1	16	16 and 11 tied	16	11
2	11		11	16
3	8 and 3 tied	8, 3 and 5 tied	5	5
4			8	8
5	5		3	3

Table 6: Supply Chain Top Risks.

Rank	I	L	I + L	2I + L	I + 2L	I × L	I^2× L	I × L^2
1	1	3	4	4	4	4	4	21
2	2	15	21	21	21	21	21	4
3	4	21	15	2	15	15	2	15
4	21	4	2	1	3	2	15	3
5	8	11	6	15	11	11	6	11
6	20	6	11	8	6	6	14	6
7	14	14	3	6	14	3	8	14
8	13	13	14	14	2	14	11	2
9	7	2	13	11	13	13	13	13
10	6	8	8	13	8	8	1	8

Table 7: NPDCombination Measure Analysis.

Top Risks	Non-Normalized Data		Normalized Data	
	Including all Columns	Excluding Columns I and L	Including all Columns	Excluding Columns I and L
1	4	4	4	4
2	21	21	21	21
3	15	15	15	15
4	2	6	2	2
5	6	11	6	6

Table 8: NPD Top Risks.

Rank	Top Supply Chain Risks	Top NPD Risks
1	Inventory Management/Stockout Risk (#16)	Organizational and Project Management Risks (#4)
2	Strategic Exposure Risk (#11)	Commercial Viability Risks (#21)
3	Market/Demand Risks (#5)	Marketing Proficiency (#15)
4	Capacity Risk (#8)	Supply Chain and Sourcing Risks (#2)
5	Supplier Reliability (#3)	Financial Risk (#6)

Table 9: Top Risk Factors.

Supply Chain Risk Factors		Likelihood of Occurrence Correlation	Impact of Risk Correlation
16	8	0.240	0.296
16	3	0.338	0.448
16	11	0.295	0.182
16	5	0.170	0.441
8	3	0.414	0.501
8	11	0.152	-0.051
8	5	0.285	0.195
3	11	0.075	0.221
3	5	0.425	0.192
11	5	-0.170	0.299

Table 10: Correlation Values Between Top Ranking Supply Chain Risk Factors.

NPD Risk Factors		Likelihood of Occurrence Correlation	Impact of Risk Correlation
6	15	0.371	0.253
6	21	0.492	0.506
6	4	0.519	0.444
6	2	0.031	0.026
15	21	0.525	0.494
15	4	0.399	0.142
15	2	0.116	0.111
21	4	0.648	0.628
21	2	0.175	0.352
4	2	0.425	0.457

Table 11: Correlation Values Between Top Ranking NPD Risk Factors.

marketing proficiency, (3) TTM risk, (21) commercial viability risks, (4) organizational and project management risks and (2) supply chain and sourcing risks.

The NPD risks also had higher Impact ratings than Likelihood ratings, as was seen with the supply chain risks. The likelihood values were multiplied by a factor of 1.34 to normalize the data, because this was the overall Impact average of 2.46 divided by the overall Likelihood average of 1.83. Risk factors 2, 3, 4, 11, 15, and 21 scored highly with both the original and normalized data. To determine the rank order, the same metric that was developed for ranking the supply chain risk factors was used. The results are shown in Table 8.

Risks 2, 4, 6, 15, and 21 ranked highest in the industry survey, with risk 4, organizational and project management risks, clearly in the top position.

Final selection of critical risk factors

Five supply chain and five NPD risk factors were identified as scoring highly in the industry survey. A complete list of these risks and their definitions are shown in Table 9. They are listed in order of their rankings, highest ranking listed first.

To determine if the survey participants were consistent with their rankings of these top risk factors, correlation values between different risk factors were calculated. These results are shown in Tables 10 and 11. In general, the correlation values between the risk factors are low. Supply chain risk factors 8 (capacity risk) and 3 (supplier reliability) have moderately high correlation values. The NPD risk factors have slightly higher correlation values. Risk factors 6 (financial risk), 21 (commercial viability risk) and 4 (organizational and project management risks) are somewhat correlated. Similarly, risk factors 15 (marketing proficiency) and 21 (commercial viability risk) are also correlated.

Conclusions

It is interesting to note that not all of the risk factors found frequently in the literature were rated highly by the industry experts. For example, the highest ranking supply chain risk factor from the industry survey was inventory management/stock out risks. This risk was only modeled in one article. A likely reason for this is that most of the supplier selection models found in the literature were high-level strategic planning models. They were designed to select the optimal set of suppliers while focusing on strategic level considerations. Once the suppliers are selected, then strategies for avoiding stock outs would be developed. Since this risk factor scored highly in the industry survey, it would be advantageous to develop a model that also takes this risk factor into consideration.

Another example is that organizational and project management risks were the highest ranked of the NPD risk factors in the industry survey. This risk factor was also only modeled in one article. The reason for the disconnect between the literature and the survey could possibly be because organizational and project management risks are more qualitative in nature. These risks include whether top management actively supports the project, whether project goals and objectives are feasible, effectiveness of the collaboration within the project team, etc. These risk factors are more difficult to include in a quantitative model, which could explain why they weren't modeled frequently. Again, it would be beneficial to develop a model that does take these risks into consideration.

It is also important to note that most of the industry survey responses were obtained from companies in the manufacturing sector. It would be interesting to redistribute the survey to a larger sample of companies from several industries, to determine if these finding hold true in other industries, and then develop a general DFSC and risk model.

An additional opportunity for future work related to this research would be to explore additional weighting schemes for analysis of the survey data. While several analysis methods were used in this research, there are also additional methods that could be utilized such as fuzzy methods.

In summary, the identification of critical risk factors was one piece of a much larger research project to develop a combination DFSC and risk tool. This tool will assist companies in selecting an optimal product design and supply chain combination and also evaluate risks associated with each of those design alternatives. This was done by modeling several of the risk factors from Table 9, and is shown in [11]. Determining which risk factors to include in the DFSC and risk tool was an important step. It is costly to include too many risk factors in the model, as the model performance (as measured by run times) degrades with each additional factor added.

Acknowledgement

This research was supported through the National Science Foundation Industry/University Cooperative Research Centers Program grant number IIP-0733386. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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